

g3. #1: 22/BNL-1505

1420



UNITED STATES ATOMIC ENERGY COMMISSION

BNL-1505

BETA RADIATION DOSAGE MEASUREMENTS

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October 1953
[TIS Issuance Date]

Brookhaven National Laboratory



Technical Information Service, Oak Ridge, Tennessee

PHYSICS

PRINTED IN USA

PRICE 20 CENTS

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BETA RADIATION DOSAGE MEASUREMENTS*

By Julia S. Marshall

INTRODUCTION

The Area Survey Group of the Health Physics Division of Brookhaven National Laboratory maintains a network of area monitoring stations for the purpose of measuring the radiation levels encountered on the laboratory site and in the surrounding area. At these stations are located Geiger-Mueller and scintillation counters for distinguishing alpha, beta and gamma activities and recording fluctuations which occur in these components of radiation. These stations are also equipped with gamma-sensitive ionization chambers and dynamic condenser electrometers¹ which are capable of measuring the gamma component in roentgens. However, no means has existed for making extensive measurements of beta dosage. The beta-sensitive ionization chamber and methods of calibration developed by Sanders² have made possible the measurement of beta dosage levels.

Beta dosage measurements have been made using beta-sensitive ionization chambers with the dynamic condenser electrometers. Three of these chambers were constructed and calibrated as described by Sanders and placed at various area monitoring stations which are regularly equipped with gamma-sensitive dynamic condenser electrometers. Measurements were made over a four-month period in an effort to determine the magnitude of the normal beta radiation background and the beta component of the dosage from the Argon-41 which is present in the cooling air of the reactor. In addition, an attempt was made to observe the pattern of beta dosage as a result of temperature inversions.

Measurements were made at four stations. In most cases the beta-sensitive chambers were placed eleven feet above the ground in a position comparable to the gamma unit. However, to obtain further data concerning beta dosage during inversions, a beta chamber at station E-2 was placed at ground level and on a platform at a distance of 5.6 feet from the ground. Since the beta-sensitive chambers do not withstand moisture, measurements were taken only during favorable weather. When left in operation overnight, each was covered with a polyethylene bag of about 5.2 mg/cm² thickness.

The walls of the beta-sensitive chambers were covered with "year-around" grade of rubber hydrochloride. Two of these had covers of 4.07 mg/cm² thickness; the third was 7.26 mg/cm². It was found that sunlight and exposure to the air caused the rubber hydrochloride to dry out and become brittle so that it was easily destroyed by any breeze. This necessitated replacing these covers frequently.

*Research carried out under the auspices of the U. S. Atomic Energy Commission.

BACKGROUND RADIATION

An examination of all background data yielded an average dosage of $18.3 \mu\text{r/hr}$ measured by the thin-walled chamber with the gamma component subtracted. However, the gamma units used to obtain the gamma dosage were not of the inverted type, that is, the case containing the dynamic condenser, the amplifier and other circuitry is situated above the ionization chamber, thus shielding the chamber preferentially from above. A correction factor of 1.2 may be applied³ to compensate for this difference. Applying this, the background figure reduces to $13.5 \mu\text{r/hr}$ with 4.07 mg/cm^2 wall thickness. The corresponding figure obtained using the chamber with 7.26 mg/cm^2 wall thickness is $7.6 \mu\text{r/hr}$. This difference in background may be explained by the fact that the 4.07 mg/cm^2 wall thickness allows the detection of alpha particles. Taking the average energy of the alpha particles of radon and its daughters, computation gives a figure of 7 mg/cm^2 necessary to stop these alphas completely if it is assumed that they are produced at the surface of the chamber wall. The total background obtained with 4.07 mg/cm^2 wall thickness, exclusive of the gamma component, can therefore be assumed to include some response to alphas as well as the beta radiation which is present. In the measurement of dosage due to Argon-41 this alpha response occurs only in the background and is, therefore, eliminated in the subtraction of the total background. As a result, the readings of the thin-walled chambers corrected for gamma response will be referred to as the beta dosage. Reference to background, as measured by the thin-walled chambers, will include some alpha response but presumes subtraction of the gamma component. This background was found to vary considerably from day to day, the measured value ranging from zero to as much as $25 \mu\text{r/hr}$.

Gamma background averages were found for each of the gamma units employed. They were as follows:

E-2	$11.6 \mu\text{r/hr}$
E-5	$10.1 \mu\text{r/hr}$
E-7	$12.2 \mu\text{r/hr}$
E-9	$10.4 \mu\text{r/hr}$

This agrees reasonably well with the average figure of $10.1 \mu\text{r/hr}$ that has been determined for a one-year period⁴.

BETA DOSAGE DUE TO ARGON-41

The attached data showing the magnitude of the beta and gamma components due to radio-argon was obtained using chambers of 4.07 mg/cm^2 wall thickness. Each of these series of measurements includes a period when other data from the monitoring stations indicate that radiation from the stack effluent was present.

The total beta dosage for a period of one hour is computed as follows. The number of cycles per hour on the Brown recorder chart from the gamma unit are counted. The number of returns made by the pen is also noted and a correction applied since each return results in a delay of thirty seconds. This procedure is repeated for the beta unit giving corrected cycles per hour. The figure for the gamma unit is multiplied by the ratio of the gamma calibration figure for the gamma unit to the gamma calibration figure for the beta unit giving the gamma response of the beta instrument. To obtain the response of the beta unit which is due only to beta dosage, the gamma figure is subtracted. This result is then multiplied by the beta calibration figure to give beta dosage in $\mu\text{r/hr}$. For example, at station E-2, using a gamma unit with a calibration figure of $5.23 \mu\text{r/cycle}$ and a beta unit with a gamma calibration figure of $4.55 \mu\text{r/cycle}$ and a beta calibration figure of $17.51 \mu\text{r/cycle}$, we have:

date, time	9/4, 1100
Cycles/hour, γ chamber	1.86
returns γ chamber	2
Corrected γ cycles/hr, γ chamber	1.89
Equivalent γ cycles/hr, β chamber	2.13
Total cycles/hr, β chamber	3.31
Returns, β chamber	4
Corrected total cycles/hr, β chamber	3.42
Beta cycles hr, β chamber	1.29
Beta dosage, $\mu\text{r/hr}$	22.59

The average total background varied widely from day to day although it remained fairly steady over reasonably short periods of time. As a result of these observations, an attempt was made to obtain background data during periods immediately preceding and following the periods when Argon dosage was being measured. An average background figure was obtained in this way for each period and this figure subtracted from the total dosage measured by the beta chamber to obtain the beta dosage due to Argon. When it was not possible to obtain background measurements in this way the average background figures given above were used in the calculations.

An examination of the data shows the variability of the relative amounts of beta and gamma dosage which are measured simultaneously due to Argon-41. This variation is to be expected since the gamma rays may be received from great distances whereas the maximum range of the Argon-41 betas in air for mean conditions at Brookhaven is 4.2 meters. If the detector were surrounded by a uniform cloud of stack effluent of dimensions large enough so that it were a semi-infinite medium for both betas and gammas from Argon-41, the gamma dosage would be about three times as large as the beta dosage at the detector. This arises from the fact that the average beta and gamma energies per disintegration are 0.46 and 1.30 mev, respectively. If the detector was immersed in a small cloud or a thin plume there would not exist a semi-infinite medium for the Argon-41 gamma rays and the beta dosage might be as large as for the large cloud but the gamma dosage comparatively small. On the other hand, a cloud of effluent remaining at a distance greater than 4.2 meters from the detector will give zero beta dosage but may result in a sizeable gamma doserate. There are some cases in the data where beta dosage exists but there is no detectable gamma dosage. Presumably gamma dosage was present in small amounts, the zero values shown being attributed to the uncertainties in the exact background figure mentioned above.

It should be noted that in very few cases does the total measured dosage exceed 0.1 mr for a period of one hour, although higher dose rates may persist for periods of a few minutes as shown below.

Total Dose Rates for Five-Minute Periods ($\mu\text{r/hr}$)

Station	Date	Time	β -Dosage	γ -Dosage	Total
E-2	9/5	0025-0030	621	11	632
E-2	9/5	1305-1310	835	27	862
E-2	9/18	1905-1910	254	10	264
E-7	9/12	1300-1305	225	29	254
E-7	10/7	1400-1405	332	20	352
E-7	10/7	2115-2120	239	11	250

It must be taken into account here that measurements were made only in relatively good weather and it is entirely possible that greater dosages may be obtained during different meteorological conditions. Greater total dosages would also be possible in the event that a period when stack effluent was present coincided with a temperature inversion due to the

combined effects of pile and radiation build-up during the inversion. Greater dose rates might also be observed close to the reactor stack under very calm wind conditions. It would also be interesting to seek out a trail from the reactor stack and measure the maximum dosage that could be obtained knowing the position of the plume or argon. It should be emphasized that these measurements were taken on the laboratory site. There is every indication from previous studies of the gamma dosage and evidence from the thin-walled GM tubes that the off-site radiation levels are considerably lower.

DOSAGE MEASUREMENTS DURING TEMPERATURE INVERSIONS

Dosage measurements were made with the thin-walled chambers during temperature inversions. A rise in the radiation background measured by these chambers was seen to follow the pattern of the temperature inversion during these periods. Dose rates were found to increase to as much as ten times the normal background level as measured by the thin-walled chambers.

A time delay was observed between the onset of the temperature inversions and the rise in radiation levels. To further analyse this effect, chambers were placed at levels of 11, 5.6 and 1.5 feet above the ground and a number of observations made at each location. The additional data confirmed the presence of this delay, its magnitude lengthening with increasing height from the ground. During temperature inversions, normal mixing of the air due to convection ceases and the radon and thoron which emanate from the ground, and their decay products, remain concentrated and do not disperse. It is, therefore, expected that a build-up of radiation would occur and that a finite time, dependent on height from the ground, would be required before this increased concentration reached the detector.

An attempt was made to duplicate the results obtained with ionization chambers by using continuous dust monitors⁵ at station E-6. The dust monitor normally in operation at this station has an intake 10 feet above ground level. An additional dust monitor was installed with intake at floor level about one foot above ground. Readings were taken every 3 hours and no delay was observed. The intake of the second dust monitor was then moved to ground level and hourly changes noted. No evidence of any difference between these two locations was found from this data. Two dust monitors were installed at the ground and 10-foot levels in station E-9 with counters at the intake. Hourly readings indicated no difference between the two locations.

The failure of the dust monitor to detect the same pattern of delay may be partially explained by the fact that the dust monitor operates primarily on thorium decay products, whereas the thin-walled chamber is predominately sensitive to radon alphas and radium decay products. The dust monitor counts only particulate matter and is, therefore, not sensitive to the built-up of radon and thoron which begins at ground level. Because of the very short half-life of thoron (54.5 sec), a new concentration of decay products is set up promptly and no delay is observed on the dust monitor, but the longer half-life of radon (3.825 days) and the rate of release of radon from the ground, cause the build-up of the activities detected by the thin-walled chamber to require a finite length of time for reaching a new equilibrium after the beginning of a period of inversion.

The standard dust monitor was designed to reduce the response to radon and thoron with alpha and beta-gamma counters placed 7 and 4- $\frac{1}{2}$ hours, respectively, from the intake. The construction of the ionization chamber with its charged center electrode and thin wall allows the field to extend outside of the wall and enables it to act somewhat as a dust collector. In some instances the decay pattern of these particles may be observed for short periods at the end of an inversion. On the other hand, the filter paper in the dust monitor moves at a constant rate. At the end of a temperature inversion the radiation falls to levels characteristic of lapse conditions in a period of one hour or less, this effect being independent of the height of the detector, as it is caused by convection currents.

In order to perform a thorough investigation, it would be necessary to take data simultaneously at different distances from the ground at the same station. Since time did not permit a more detailed study of this phenomenon, this merely indicates the presence of the effect.

Figures 1 and 2 illustrate the manner in which the pattern of the temperature inversion is followed by the increase in radiation as measured by the thin-walled chambers. Delays of about one and one-half hours can be observed.

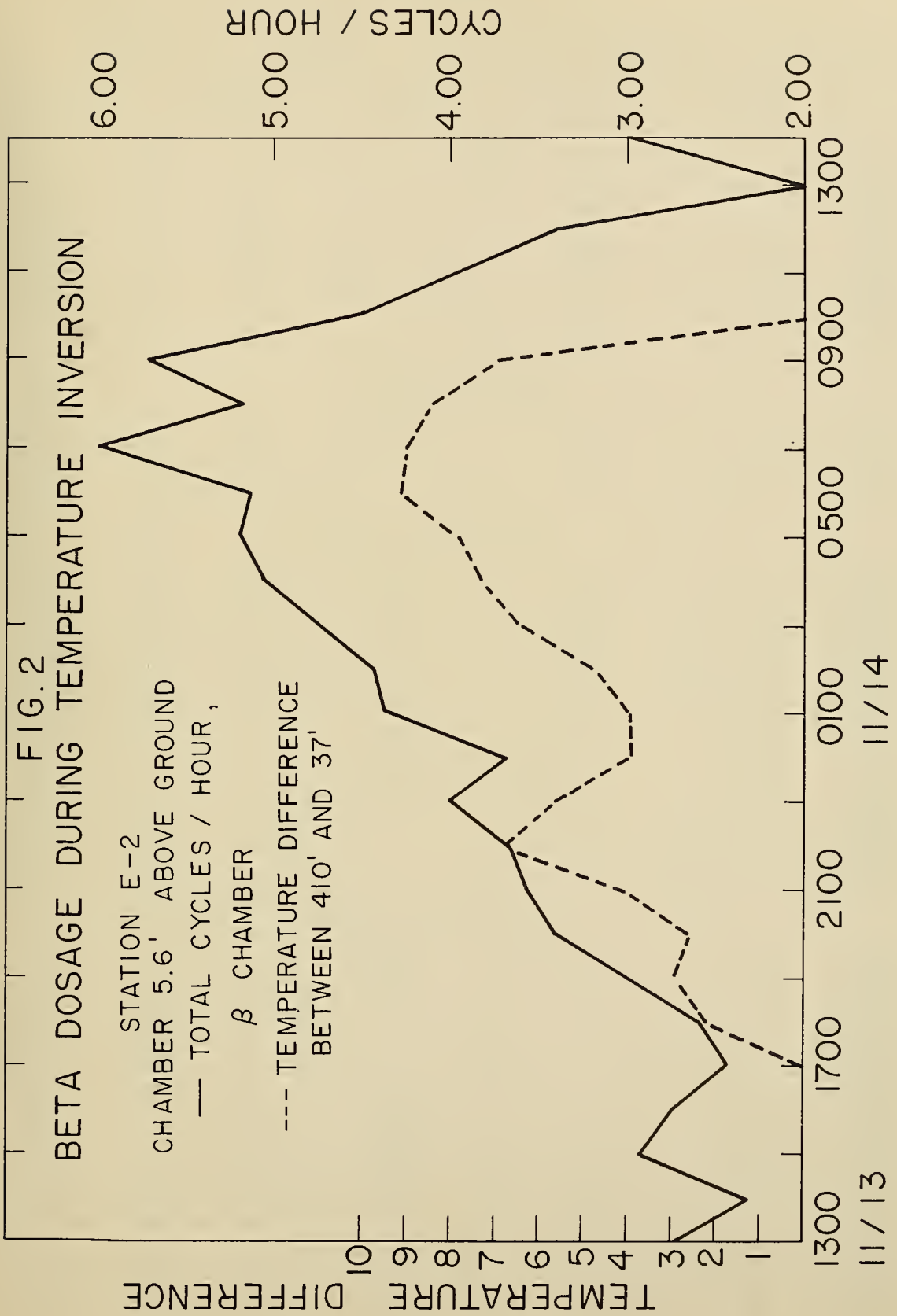
CONCLUSION

There are several difficulties encountered when one endeavors to make accurate measurements of the beta component of Argon-41 from the reactor. The principal problem is the extreme variation in the level of normal beta background radiation. This introduces a considerable error in measurements taken over extended periods of time. Secondly, for any degree of accuracy, it is necessary to have a gamma detector which has the same geometry as the beta unit. The 1.2 correction factor was calculated for a non-inverted chamber assuming complete immersion; i.e. a hemispherical source. Calculations have also been made for a line source at varying distances. For instance, for a plume 100 meters directly above the detector, the ratio of true to measured gamma dose rate would be 1.52. If the plume were at a height of 100 meters and displaced laterally from the detector by 300 meters, the correction factor would be only 1.13. However, such figures cannot readily be applied to dosage measurements of this type where the position of the plume with respect to the detector is unknown. A third inaccuracy is introduced by the ability of the thin-walled chambers to detect alpha particles. A minimum of 7 mg/cm² wall thickness would be desirable to minimize the background correction and fluctuation in background. A fourth obstacle is the necessity for good weather conditions before such measurements can be made, due to the fragile nature of the chambers. However, from data obtained in this way, a reasonable estimate may be made of the magnitude of the beta radiation background, the beta dosage due to radioargon, and the increase in background radiation levels during temperature inversions.

REFERENCES

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3. Memo: P. H. Lowry to M. M. Weiss, August 7, 1951; The Effect of a Line Source on Non-uniform Response of Ionization Chamber.
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5. loc. cit.; p. 95.





Beta, Gamma and Total Dosage from Argon-41 Effluent from the Reactor, r/hr

Hour	γ Dosage as Measured by γ Chamber	β Dosage as Measured by β Chamber	γ Dosage Due to Argon	β Dosage Due to Argon	Total Dosage From Pile
1000	9.93	13.8	0	0	0
1100	9.99	11.6	0	0	0
1200	10.8	27.1	0	12.2	12.2
1300	27.0	71.1	15.4	56.1	71.5
1400	34.9	37.8	23.3	22.8	46.1
1500	34.6	78.6	23.1	63.6	86.7
1600	34.2	.87	22.6	0	22.6
1700	10.0	29.1	0	14.1	14.1

Station E-2, 9/5/52

1500	25.0	14.9	13.4	9.80	23.2
1600	14.6	49.0	3.08	44.0	47.0
1700	12.3	0	.78	0	.78
1800	8.52	10.2	0	5.08	5.08

Station E-2, 9/14/52

0400	12.7	37.3	1.10	27.6	28.7
0500	13.1	26.3	1.52	16.6	18.1
0600	12.9	16.5	1.31	6.81	8.12
0700	12.1	23.6	.52	14.0	14.5
0800	11.2	20.3	0	10.7	10.7
0900	12.9	8.93	1.36	0	1.36
1000	13.6	4.38	2.04	0	2.04
1100	11.6	11.6	0	1.91	1.91
1200	12.1	7.35	.57	0	.57
1300	11.0	8.93	0	0	0
1400	11.2	6.65	0	0	0
1500	10.3	8.23	0	0	0
1600	11.4	5.08	0	0	0

Station E-2, 9/14-9/15/52

1800	11.6	3.68	.05	0	.05
1900	11.6	0	.05	0	.05
2000	10.6	7.53	0	0	0
2100	13.3	0	1.72	0	1.72
2200	11.3	1.22	0	0	0
2300	14.3	.70	2.77	0	2.77
2400	15.0	0	3.45	0	3.45
0100	14.7	0	3.14	0	3.14
0200	15.9	0	4.34	0	4.34
0300	17.5	18.7	5.96	14.9	20.9
0400	16.4	20.1	4.86	16.3	21.2
0500	21.4	0	9.88	0	9.88
0600	26.5	0	15.0	0	15.0
0700	26.3	0	14.7	0	14.7
0800	27.9	35.4	16.4	31.5	47.9
0900	44.1	0	32.6	0	32.6

Hour	γ Dosage as Measured by γ Chamber	β Dosage as Measured by β Chamber	γ Dosage Due to Argon	β Dosage Due to Argon	Total Dosage From Pile
1000	44.1	0	32.6	0	32.6
1100	34.8	28.0	23.2	24.2	57.4
1200	52.5	0	40.9	0	40.9
1300	38.6	0	27.1	0	27.1
1400	13.0	.18	1.41	0	1.41
1500	12.3	1.40	.78	0	.78
1600	12.4	.53	.89	0	.89
1700	10.5	5.60	0	1.76	1.76
1800	12.1	.18	.57	0	.57
1900	13.9	0	2.35	0	2.35

Station E-2, 9/19/52

0100	10.1	7.18	0	0	0
0200	10.5	6.83	0	0	0
0300	10.6	3.33	0	0	0
0400	9.94	10.9	0	0	0
0500	11.5	14.4	0	3.00	3.00
0600	10.1	3.15	0	0	0
0700	4.65	30.1	0	18.8	18.8
0800	10.1	4.70	0	0	0
0900	9.68	22.8	0	11.4	11.4
1000	9.88	21.5	0	10.2	10.2
1100	9.83	16.8	0	5.45	5.45
1200	9.62	16.3	0	4.92	4.92
1300	10.1	45.5	0	34.2	34.2
1400	10.5	1.75	0	0	0

Station E-2, 11/6/52

1200	12.2	16.8	.62	3.34	3.96
1300	12.1	19.1	.57	5.61	6.11
1400	12.4	10.7	.88	0	.88
1500	11.8	15.9	.26	2.46	2.72
1600	11.1	13.5	0	.01	.01

Station E-7, 9/12/52

1000	16.0	21.4	3.80	3.15	6.95
1100	30.3	88.9	18.1	70.6	78.7
1200	23.5	60.6	11.2	42.4	53.6
1300	35.2	80.7	23.0	62.4	85.4
1400	28.8	76.6	16.6	58.3	74.9

Station E-7, 9/30-10/1/52

1100	14.2	23.0	2.01	6.22	8.23
1200	12.9	28.6	.62	11.9	12.5
1300	14.0	29.1	1.74	12.4	14.1
1400	22.0	44.4	9.73	27.6	37.3
1500	41.4	76.1	29.1	59.3	89.4
1600	34.5	73.7	22.2	56.9	79.1
1800	13.5	39.2	1.29	22.5	23.8

Hour	γ Dosage as Measured by γ Chamber	β Dosage as Measured by β Chamber	γ Dosage Due to Argon	β Dosage Due to Argon	Total Dosage From Pile
1900	15.7	16.4	3.47	0	3.47
2000	3.66	32.9	0	16.2	16.2
2100	12.2	19.5	0	2.80	2.80
2200	12.4	36.3	.17	19.6	19.8
2300	12.5	15.9	.22	0	.22
2400	15.7	3.08	3.47	0	3.47
0100	9.05	9.59	0	0	0
0200	12.1	16.8	0	.06	.06
0300	12.6	13.5	.39	0	.39
0400	12.4	17.3	.18	.67	.85
0500	13.1	15.9	.90	0	.90
0600	12.9	19.4	.67	2.63	3.30
0700	14.1	17.8	1.85	1.09	2.94
0800	15.5	15.6	3.25	0	3.25

Station E-7, 10/2-10/3/52

2100	16.4	51.2	4.14	33.0	37.1
2200	12.9	28.8	.62	10.5	11.1
2300	20.9	30.3	8.44	12.1	20.5
2400	18.0	36.8	5.76	18.6	24.4
0100	16.4	58.9	4.19	40.7	44.9
0200	14.8	34.1	2.57	15.8	18.4
0300	18.2	34.8	5.98	16.5	22.5
0400	26.0	50.7	13.8	32.4	46.2
0500	19.1	59.1	6.82	40.8	47.6
0600	24.3	78.8	12.0	60.5	72.5

Station E-7, 10/7-10/8/52

0900	13.6	15.0	1.34	0	1.34
1000	25.7	32.4	13.4	16.7	20.1
1100	13.6	37.5	1.34	21.8	23.1
1200	27.7	33.6	15.5	17.9	33.4
1300	26.2	30.3	14.0	14.6	28.6
1400	23.9	38.0	11.7	22.3	34.0
1500	20.2	40.6	8.00	24.9	32.9
1600	30.3	56.7	18.1	41.0	59.1
1700	32.9	68.0	20.6	52.3	72.9
1800	9.56	31.2	0	15.5	15.5
1900	10.7	20.6	0	4.86	4.86
2000	11.2	15.8	0	.06	.06
2100	11.6	14.4	0	0	0
2200	14.5	15.1	2.22	0	2.22
2300	11.4	14.9	0	0	0
2400	11.4	14.2	0	0	0
0100	11.0	16.6	0	.92	.92
0200	11.0	17.3	0	1.60	1.60
0300	11.4	16.6	0	.92	.92
0400	11.2	15.6	0	0	0
0500	11.2	17.0	0	1.26	1.26
0600	11.2	13.9	0	0	0
0700	11.4	17.1	0	1.43	1.43

Hour	γ Dosage as Measured by γ Chamber	β Dosage as Measured by β Chamber	γ Dosage Due to Argon	β Dosage Due to Argon	Total Dosage From Pile
Station E-5, 10/28/52					
1100	12.4	22.1	2.28	1.46	3.74
1200	13.1	22.8	3.01	12.1	15.1
1300	21.0	32.4	10.9	11.7	22.6
1400	11.4	23.0	1.32	2.31	3.63
1500	9.29	20.9	0	.26	.26
1600	9.71	20.4	0	0	0
Station E-5, 10/30/52					
1000	12.4	46.1	2.28	32.6	34.9
1100	17.0	0	6.87	0	6.87
1200	11.6	23.8	1.54	10.3	11.8
1300	11.3	26.4	1.22	12.9	14.1
1400	10.0	84.4	0	71.0	71.0
1500	20.5	8.56	10.5	0	10.5
1800	29.5	0	19.4	0	19.4
1900	35.2	0	25.1	0	25.1
2000	44.1	13.7	34.0	.23	34.2
2100	43.4	17.5	33.3	4.00	37.3
2200	11.2	110.	1.17	96.3	97.5
2300	49.7	0	39.7	0	39.7
2400	26.6	8.91	16.5	0	16.5
Station E-5, 11/5-11/6/52					
2000	10.4	12.7	.32	3.12	3.44
2100	10.5	8.57	.43	0	.43
2200	9.45	13.7	0	4.14	4.14
0200	10.2	6.85	.11	0	.11
0300	10.3	9.08	.22	0	.22
0400	10.1	12.0	0	2.43	2.43
0500	9.82	12.3	0	2.77	2.77
0600	13.6	11.0	3.49	1.40	4.89
0700	17.7	27.9	7.61	18.4	26.0
0800	15.4	12.8	5.34	3.29	8.93
0900	11.4	11.3	1.27	1.75	3.02
Station E-5, 11/6-11/7/52					
1800	9.93	9.25	0	0	0
1900	9.77	13.9	0	.19	.19
2000	9.98	14.0	0	.36	.36
2100	9.56	16.3	0	2.58	2.58
2200	10.1	14.4	0	.70	.70
2300	10.1	13.2	.06	0	.06
2400	10.1	11.8	.06	0	.06
0100	10.3	15.1	.22	1.38	1.60
0200	10.1	14.4	0.	.70	.70
0300	10.7	14.6	.59	.87	1.46
0400	12.6	12.7	2.54	0	2.54
0500	12.2	15.9	12.2	2.24	14.4
0600	23.4	15.4	13.3	1.73	15.0
0700	19.3	11.3	9.19	0	9.19
0800	13.7	8.9	3.60	0	3.60

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